the meteorological magazine

Meteorological glossary, 5th edition

This glossary has been revised and enlarged to include a number of new entries and revisions stemming from recent advances made, for example, in numerical prediction and satellite meteorology. Although some traditional British units are still used for the convenience of user interests, the Système International (SI) units have been generally adopted.

£2·75 (£2·96 by post)

HMSO BOOKS

Marine climatological summaries for the Atlantic Ocean east of 50°W and north of 20°N, 1964

These summaries are part of a series covering the oceans of the world which are to be published by various countries, including the U.K., in accordance with a scheme sponsored by the World Meteorological Organization. The observations recorded in the tables are made aboard ships on passage or at ocean weather stations. Production of the tables was facilitated by the use of a computer for processing the data.

£6 (£6·25 by post)

HMSO BOOKS

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OPENING OF THE RICHARDSON WING
BY THE PRIME MINISTER

On the afternoon of 6 October 1972, in warm and sunny weather befitting
the occasion, the Meteorological Office was honoured by a visit from the
Prime Minister, the Rt Hon. Edward Heath, M.B.E., M.P., who came to
perform the official opening of the new wing of the Headquarters building
at Bracknell. The new wing, which houses the Central Forecasting Office,
the Telecommunications Centre and the Computing Laboratory, has been
named after Dr L. F. Richardson, F.R.S., the pioneer of numerical weather
forecasting.

The ceremony was held in the flower-decked entrance hall of the Richardson
Wing before an assembly of distinguished guests, including six members of
the Richardson family, and about 350 members of the staff of the Office.

The Prime Minister was greeted on arrival at the main entrance of the
FitzRoy Wing by Mr Antony Lambton, M.P., Parliamentary Under-
Secretary of State for Defence for the Royal Air Force, and Dr B. J. Mason,
F.R.S., Director-General of the Meteorological Office. After signing the
Visitors' Book (Plates I and IV), and having been introduced to the senior
directors, the Prime Minister proceeded to the entrance hall of the Richardson
Wing (Plate II). Here an address of welcome was given by Dr Mason, in the
course of which he recalled the achievements of Lewis Fry Richardson
(Plate VI) and said that he was proud to name the new wing after this
remarkable man, in the presence of his son and daughter.

In his reply the Prime Minister said that it had been a happy inspiration
to name the new building after Lewis Richardson, and that the computer
and other facilities that it contained were unrivalled in Europe. He hoped
very much that the Government's offer to house the European Centre for
Medium-Range Forecasts at Shinfield Park, Reading, would be accepted.
After some appreciative remarks about the value of the forecasts he received
as a yachtsman from the Meteorological Office, the Prime Minister unveiled
a commemorative plaque (Plates III and V).

After a break for tea with official guests and senior staff, during which
Dr Mason presented him with an inscribed copy of *Meteorology for mariners*

(Plate VII), the Prime Minister was escorted by Dr Mason and Mr P. J. Meade, Director of Services, round the new building. In the Central Forecasting Office (Plate XI) he was able to see how forecasts based on the new 10-level hemispheric model are made for up to three days ahead and extended to five days by more subjective methods. He was shown a striking selection of satellite photographs, the radar display, and ships being routed across both the Atlantic and Pacific Oceans. In the Telecommunications Centre (Plate IX) he was able to see the new facsimile switching centre (Plate X) and the computer-controlled message-switching system that will soon link Bracknell with Washington, Paris and Offenbach on the Main Trunk Circuit of the World Weather Watch. In the Computing Laboratory (Plates XII and XIII), the power of the new IBM 360/195 computer, which besides its main forecasting role, already handles about 2500 research and other tasks a week, was explained and Mr Heath saw how charts are plotted and drawn at very high speed on the cathode-ray-tube plotter.

The Prime Minister, who appeared to thoroughly enjoy his visit, showed a lively interest in everything he saw, and spoke to several members of the staff during the tour. He later wrote an appreciative letter to the Director-General which is reproduced in Plate VIII.

The unveiling of the plaque by the Prime Minister, film showing the operations and facilities in the new wing, and an interview with the Director-General were shown on BBC Television News at 7.30 and 9 p.m. on the same day.

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THE RICHARDSON WING*

The Richardson Wing forms the fourth side of a square around a grassed court, the other three sides consisting of the original building. It is a fine new building of five storeys designed and built by the Department of the Environment and houses the Meteorological Office operational centre containing the Computer Laboratory (ground floor), the Telecommunications Centre (first floor), and the Central Forecasting Office (second floor). Administrative offices occupy the third floor and heating, ventilating and electric plant the lower ground floor.

Air-conditioning plant maintains prescribed temperature and humidity conditions and the control system of the plant enables a fault to be located rapidly in the event of a failure.

An electrical passenger lift has been installed to all floors and there are also electric document-conveyors to suit operational requirements.

The Computer Laboratory. The development of a sophisticated 10-level atmospheric model and other projects requiring much larger computer power

* The main sections of this article were contributed by Messrs G. A. Howkins, D. McNaughton and C. Alderson respectively.

than was provided by the KDF9 computer (COMET) has led to the purchase in 1971 of an International Business Machines (IBM) 360/195 computer. The IBM 360/195 is one of the most powerful computers in the world, capable of about 10 million instructions per second, and currently only three such computers are installed in Europe. The Bracknell installation, including its air-conditioning plant and power supplies, occupies the whole of the ground floor and a substantial part of the lower ground floor of the new Richardson Wing.

The computer system is based on the IBM 360/195 central processor with 1 million characters of main storage and over 1200 million characters of fast on-line disc storage. A wide variety of standard input/output peripherals are included, such as card readers/punches, paper-tape readers/punches, line printers and magnetic-tape drives. The computer configuration provides a substantial degree of protection against peripheral failures which might interrupt operational forecasting schedules. In addition to the standard peripherals, there are a Calcomp computer output on microfilm system for plotting and line-drawing functions, two IBM 2250 graphic cathode-ray-tube (CRT) display units and several IBM teletypewriters and CRT alphanumeric terminals providing remote job-entry facilities.

The new system was installed in October 1971, only three weeks after the planned installation date, and after trials supervised by the Ministry of Technology was handed over to the Meteorological Office shortly before Christmas 1971. A work load of over 1000 jobs per day had been absorbed by the New Year and, in spite of interruptions to electrical power supplies, a hemispheric version of the new 10-level model was implemented operationally on 1 August 1972. Also routine computations of the new fine-scale 10-level model for the British Isles are made twice daily.

Meteorological Telecommunications Centre. For many years the main 'tools' of communication have been teleprinters operating at comparatively slow speeds either by means of land-line links or through radio transmissions. The Bracknell Telecommunications Centre still relies heavily on these machines and, for purely internal communications between the U.K. outstations and Bracknell, will continue to do so for some years to come. But the picture is changing and Bracknell, in common with similar large centres in other parts of the world, has embarked on a programme of automation which will lead before long to the replacement of many of the slow-speed teleprinter channels by which information is received from Europe, North America and farther afield, by a new and very sophisticated computer-controlled message-switching system. In the new Automated Complex two Marconi *Myriad II* digital computers are already controlling the flow of meteorological traffic at speeds up to about 50 times that of a conventional teleprinter along the new 'main highway' provided by the Main Trunk Circuit which links Bracknell with Washington in the west and Paris and Offenbach in the east. Soon after this article is published the first part of the system will become operational and there will be a significant speeding up of the reception of information from a very wide area. Later, the extension of the Main Trunk Circuit through Moscow, New Delhi, Melbourne and Tokyo to encircle the globe, the implementation of various regional branches and circuits and the introduction of more automation in the Telecommunica-

tions Centre, providing (amongst other refinements) a 'preferred order' system for domestic teleprinter broadcasts and an electronic interface with the IBM 360/195 which produces forecasts, will still further improve and speed up the services provided.

Apart from the raw material of meteorological exchange there is an important requirement for the distribution of processed information both actual and forecast in various pictorial forms, e.g. charts of contours, isotachs and isotherms at various levels in the atmosphere. The Facsimile Section meets this requirement and operates four facsimile broadcasts almost continuously. One provides a service by land-line to most meteorological offices in the United Kingdom and consists mainly of support for their fore-casting activities from the resources of the Central Forecasting Office. Two radio-facsimile broadcasts meet agreed international requirements for processed charts from Bracknell and a number of other important centres (including Moscow and Washington) for the general support of meteorological services, including those devoted to maritime and aviation activities. A further land-line service transmits charts produced by the IBM 360/195 direct to the large aviation offices at London/Heathrow Airport and the Headquarters of Strike Command and No. 46 Group, RAF. Bracknell arranges for the receipt of facsimile products from a number of other countries, and the exchange of similar products (alternately with alphanumeric data) will have an important place in the Main Trunk Circuit. There are also extensive arrangements for recording on magnetic tape so that charts can be accepted as they become available and fed into the various parts of the system when they are required.

Already the Telecommunications Centre receives and transmits more than $1\frac{1}{4}$ million groups of weather information a day, as well as some 1000 facsimile weather charts and a very large number of plain-language forecasts and messages. As the volume and speed of traffic increases and as new methods and procedures are introduced the Telecommunications Centre will vary its facilities and services to meet changing needs. The new accommodation provided in the Richardson Wing will make a significant contribution to this development.

Central Forecasting Office. The Central Forecasting Office (CFO) entrance vestibule has a comfortable waiting area, decorated with a very fine series of cloud studies by R. K. Pilsbury, F.R.P.S. There is a Visitors' Room with a permanent display of information and of the charts used in CFO. The work of CFO is usually described to parties of visitors in this room. Met O 2b, who provide operational numerical forecasting program support, occupy the western end of the floor, together with the Storm Tide Warning Service and the *Daily Weather Report* office.

The forecast room and adjoining offices are air-conditioned and are completely carpeted. Benches and light-tables were specially designed and are grouped into convenient working units. The senior forecaster and deputy, and the medium-range and British Isles forecasters occupy one unit, ships' routeing section another and upper-air forecasters and plotters a further set of units. Surface plotters and the supervisors have their own sets of benches, as also has the Sea Ice Section. Along one wall are the warning display boards. These are made of stainless steel, with outlines of countries and

warning areas etched in, and magnetic plastic characters are used to mark up the warnings state.

Adjoining the upper-air section is an IBM 2250 graphic display unit which is linked directly to the main computer on the ground floor. It is intended to use this unit in a number of ways including some control aspects of the numerical forecast program suite. Immediately in front of the senior forecaster is a weather radar display; this is transmitted via closed-circuit television from the radar display which is housed in a room which is also used for the conversion of satellite pictures into nephanalyses and for adding the geographical co-ordinates to such pictures.

Another room off the main forecast area houses the photo-reproduction equipment, which comprises an ADMEL PD 600 copier, used for making copies of charts, for distribution in the forecast room and to other branches and other government departments, and a Rank Xerox 1824 universal printer, which enlarges and prints, from 35-mm film produced by the Calcomp 1670 housed in the Computer Laboratory, upper-air analyses and prognostic charts which are subsequently broadcast on facsimile.

In the corner of the forecast room are lifts, connecting with the Meteorological Telecommunications Centre (Met TC) and the Computer Laboratory, which are used to pass information both to and from CFO. There is also a hand hoist, which connects directly with the facsimile area of Met TC, and from the Editing Room a conveyor bringing teleprinter data for plotting on the working charts by the assistant staff.

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THE METEOROLOGICAL OFFICE 360/195 COMPUTING SYSTEM

By G. A. HOWKINS, M.B.E.

Summary. The article is in three parts. The first part outlines the main data-processing functions to be fulfilled by the new computer and the second part outlines progress made prior to installation and during the first year of operation. The last part outlines, with the minimum of technical terms, some of the differences between the three computers used by the Meteorological Office and describes several of the more important features of the new configuration. A technical comparison of the three systems is made in an Appendix.

Introduction. A review of Meteorological Office computing requirements for the next decade was completed in 1968. The review revealed that, of 16 branches already involved in computing, 14 expected only a modest increase in their computing activities and much of this increase would depend on extended facilities for data archiving and retrieval. However, 2 branches, Met O 11 — Forecasting Research — and Met O 20 — Dynamical Climatology — were heavily involved in atmospheric modelling and foresaw the need for a major increase in computing power. Also the Telecommunications Branch, Met O 5, and Operational Instrumentation Branch, Met O 16, who were not at that time involved in computing, planned extensive automation of the telecommunications functions and the upper-air sounding networks,

but this new work would be done by means of dedicated computers which would place little or no demands on the main computer serving the rest of the Office.

The main data-processing functions.

Atmospheric modelling. Lewis Fry Richardson[1] first conceived the idea of computing forecasts 50 years ago but no real progress could be made in this field until electronic digital computers had been developed. The Meteorological Office first started research into such schemes in the early 1950s, hiring time on suitable computers, and regular experiments were mounted on the first Meteorological Office computer — a Ferranti *Mercury* (METEOR) installed in 1958. Regular operational forecasts were introduced when the more powerful English Electric-Leo KDF9 (COMET) replaced METEOR in 1965. COMET was used from 1966 to 1972 to compute forecasts twice daily using a 3-level 'dry' atmospheric model, a 24-hour forecast taking about 20 minutes to compute (about 1 hour if data input, analysis and printing of results are included). Meanwhile the Forecasting Research Branch (Met O 11) began experiments on a more complex 10-level 'moist' model potentially capable of quantitative forecasts of precipitation. Computations for this model were first done on the International Computers Limited *Atlas* computer at Manchester University and subsequently on the *Atlas* computer at the Science Research Council establishment at Chilton. The *Atlas* computer is about 5 times faster than COMET but the new model required about 40 times more instructions than the 3-level model and a 24-hour forecast took several hours to compute on *Atlas*. While Met O 11 were experimenting with the 10-level model for short-range forecasting, Met O 20, the Dynamical Climatology Branch, were developing models to compute experimentally changes in hemispheric circulation taking place over a period of about 3 months. A large amount of computing was involved in each experiment because the forecasting interval was necessarily long and the area covered large. The computing capacity required by Met O 20 was at least as great as that required by Met O 11 for the new 10-level short-range forecasting models.

The encouraging results obtained on the Chilton *Atlas* provided the main reason for the purchase of a new high-speed computer system which had to be at least 10 times faster than *Atlas* to complete the development of the Met O 11 and Met O 20 models and to run the Met O 11 model for operational forecasting.

The operational numerical forecasting suite. Logically an operational numerical forecasting suite consists of four main groups of programs which :

    (a) check and store the observations which form the basic data,
    (b) produce analyses,
    (c) compute forecasts,
and (d) output results.

The last step involves not only the presentation of results in the forms required by forecasters but also a considerable amount of computation to derive results such as tropopause data, and wind speeds and directions for pressure levels and along specified aviation routes, none of which are produced directly in computing the forecasting model.

In the KDF9 forecast suite, based on the 3-level 'dry' atmospheric model and written jointly by Met O 2, the Central Forecasting Branch, and Met O 11,

the Forecasting Research Branch, data handling was confined to those items required specifically for the production of the analysed fields from which the forecast is computed. Other data, e.g. weather types, visibility, were not stored. In the new forecast suite, data handling was undertaken by Met O 12, the Data Processing Branch, and a more general approach was taken because it was expected that in the future more time-critical applications would be made of all types of synoptic data (e.g. for automated chart plotting). This led to the concept of a synoptic data bank in which all types of data received through the telecommunications channels in the past 60 hours would be stored 'on-line' to the computer on magnetic discs. While on disc, recognized data would undergo quality controls in several stages. Also generalized retrieval routines would be written to enable users to select and retrieve data to suit their requirements. After 60 hours residence on-line to the computer, all data, whether sorted into code types or not, would be stored on magnetic tape for permanent retention in archives. Thus the synoptic data bank is designed to provide the maximum amount of reliable data for time-critical projects run at various times of day and, to realize the full potential, data should be received continuously from the telecommunications channels.

The early versions of the synoptic data bank programs were written to provide only the essential data for known projects, such as the operational forecasts, but the design was such that additional programs could be introduced as the need arose. Also all data, whatever the code, were preserved and it will be possible to re-examine the stored data using later programs to extract more data.

In addition to retention in archives as a permanent synoptic data bank of quality-controlled observations, the data will be used by Met O 22, the newly formed Systems Development Branch, as one of several sources of data for a permanent climatological archive of data stored as time series for each each reporting station.

Because of this general approach adopted by Met O 12 for the synoptic data bank, Met O 2(b), the numerical-forecasting section of the Central Forecasting Office (CFO), wrote routines to select from the data bank those meteorological data required by the analysis programs, i.e. to set up the basic analysis data sets (BADS). The Met O 11 analysis programs are not very different in concept from those in the earlier 3-level suite but humidity analyses were required and because of the finer structure of the new model extra care was necessary to obtain 3-dimensional consistency in the analyses for the 10 levels. Met O 11 developed two forecast suites, both based on the 10-level atmospheric model. The 'octagon' forecast suite covers an octagonal area centred on the North Pole and extending over most of the northern hemisphere north of about 15°N. The octagon suite is designed to fulfil the functions of the 3-level model in providing forecasts for civil and military aviation and guide-line forecasts for weather over the CFO area of responsibility up to 72 hours ahead. The octagon model employs a grid of about 3000 points at approximately 300-km intervals at 60°N and the time step used to compute a forecast is 400 seconds. The finer-scale rectangle forecast suite, designed primarily to produce quantitative precipitation forecasts over the British Isles and near-European areas, covers about one-tenth of the area covered by the octagon and includes much of the North Atlantic Ocean and western

Europe. The distance between grid points is 100 km and the time step used
is 150 seconds. As there are about the same number of grid points in the two
versions of the 10-level model, the time taken for computation depends on
the time step chosen, the rectangle taking about 35 minutes and the octagon
13 minutes for a 24-hour forecast on the 360/195.

Met O 2(b) operational output routines convert the forecast results to
fields of data for standard pressure surfaces. The printed results are broadly
similar to those from the 3-level model including a considerable amount
of derived data such as that on the tropopause from the Brady modelling
technique,[2] and wind speeds and temperatures for standard pressure surfaces
along certain aviation routes and at major airports. Winds and temperatures
for routes are punched directly to paper tape for teleprinter transmission
to London/Heathrow Airport and Prestwick Airport where these data are
fed into flight-planning and flight-control computers. Most of the output
for standard pressure levels is produced on fast 2000-line-per-minute printers
and is printed as contours in the form of 'zebra' prints on special continuous
stationery with a chart background. These charts display isopleths of wind
direction, wind speed and temperature, which are used as the basis of flight-
planning documents for both civil and military aviation.

Data archiving and retrieval. The 1968 review of requirements showed that
archiving and retrieval of data would increase steadily as new or expanding
projects such as the Dee Valley rainfall study[3] and medium-range and
seasonal forecasting studies generated new data banks or as new applications
were developed for the large volumes of synoptic data already collected
daily from much of the northern hemisphere. In particular, extended automa-
tion of time-critical functions such as line drawing and plotting of synoptic
charts and preparation of the daily, monthly and annual publications would
lead to increased use of a wider range of data than that currently used for
operational numerical forecasting with the 3-level 'dry' atmospheric model.
However, the processing power required for such functions is very small by
comparison with the power required for computing atmospheric models for
operational numerical forecasting and any processor capable of the latter
would easily cope with archiving functions if sufficient fast on-line storage
and archival storage were provided.

General computing service. In addition to the data archiving, atmospheric
modelling and operational forecasting functions already described, there was
a requirement for a general computing service covering the work of 16 of
the 22 branches in the Meteorological Office. This embodies a whole spectrum
of work from the short development jobs with little or no data or storage
requirements to the very long and complex runs for proving a new operational
forecasting suite. It is comparatively easy to provide a quick 'turn round'
for jobs which require few facilities and take only a short time to compute
but difficult to provide an acceptable service for jobs requiring a large share
of the facilities and taking a long time to compute.

Pre-installation facilities and the first year of operation.

Pre-installation. An operational requirement for a new computing system
was drawn up in 1968 and negotiations with several major manufacturers
culminated in the ordering on 31 December 1969 from International Business

Machines Ltd (IBM) of a configuration based on the IBM 360/195 central processor. After the order had been placed the company made available programmer training facilities at Sudbury and by December 1971 when the computer was installed at Bracknell, 160 staff had been trained in the 'high-level' language FORTRAN IV and 70 were also trained in the 'low-level' IBM language known as ASSEMBLER. The company also made available facilities for program development at their Customer Test Centre (CTC) at Croydon, mostly on an IBM 360/65 computer, and at Poughkeepsie (U.S.A.), mostly on an IBM 360/195. The former, although much slower than the 360/195, belongs to the same series and programs written for the 360/65 will run on a 360/195. From October 1970 to December 1971, when the new system was available at Bracknell, a total of 240 hours of computer time were used at Poughkeepsie by Met O 2, 11 and 12 to develop operational forecasting suites based on the new 10-level model and by Met O 20 for their hemispheric model. All 16 branches involved in computing made use of the Croydon facilities to convert projects already running on COMET and to start new work for the 360/195.

Three methods were used : most jobs were delivered to CTC by a security service van for computer processing at night and return to Bracknell by road early on the following morning, others were taken to Croydon by individual programmers and, with effect from October 1970, day-time runs could be obtained for all but the largest programs by submission through a card-reader/line-printer terminal installed at Bracknell and linked by telephone line to Croydon. By the time that the 360/195 was available at Bracknell the weekly total of Meteorological Office jobs run at Croydon had exceeded 1000 and it was imperative that the new installation at Bracknell should absorb this work load smoothly and over a short period of time to avoid delaying the work of all branches. During the pre-installation period, and to the present date, IBM provided systems engineers at Bracknell to assist branches, as required, in the development of their new programs.

The first year of operation. The 360/195 was installed in the new Richardson Wing in October 1971 (see Plate XII), passed its acceptance tests by mid-December and by the end of that month was carrying the full work load from Croydon, together with some of the large jobs from Poughkeepsie. During the first four months, despite power problems and teething troubles generally, Met O 2, 11 and 12 made every effort to bring the development and testing of the new 10-level forecasting suites to an operational state. Both the octagon and rectangle suites were run twice daily on most days from March onwards. Met O 2 also had the responsibility of completing the development of a program to simulate the functions of the KDF9 COMET on an IBM 360/195 machine using a 'simulator' program purchased from the Nuclear Power Group, Knutsford, for the purpose of running the 3-level program suite on the 360/195. The simulator makes it possible to run programs written in USER code for KDF9 on an IBM 360 series computer without reprogramming in IBM ASSEMBLER code. This method, although very slow in computation, avoided reprogramming the complex 3-level suite which was only required for a short period in the new 360 system.

Apart from a few short breaks of service the 360/195 was operated 14 hours per day seven days per week from 18 December 1971 to 21 March 1972,

when full 24-hour operation was introduced. Full 24-hour operation, including operation of the 3-level forecasting suite, also continued on COMET until the end of April 1972, after which COMET operations were reduced to 14 hours per day. The 3-level suite also ran on the 360/195 under the simulator program from 21 March and on 1 May the output from the new computer system assumed the operational role.

By the middle of 1972 the 10-level octagon suite was judged to be sufficiently developed for it to replace the 3-level suite as the main operational model and operation of the latter ceased on 31 July. Met O 11 are continuing the development of the 10-level rectangle model, which is intended primarily for quantitative precipitation forecasts, and forecasts are computed twice daily from the same data as those applied to the operational octagon suite.

It had been planned to transfer synoptic data between the telecommunications computers and the 360/195 by means of a high-speed electronic interface but it became clear that the telecommunications computers would not be available when the 360/195 was installed and it was necessary to develop programs to process data from 5-hole Murray-code tape punched in the telecommunications centre. The method is slow and cumbersome and poses serious problems which must be overcome as more frequent time-critical and data-dependent operations such as chart plotting are introduced.

Although the main emphasis in the first year has been on the development and introduction of the new forecasting models, the work of other branches has progressed well and the total of development jobs has risen from 1000 per week at installation to about 2500 per week by November 1972.

The new hardware and control programs. In digital computers the binary forms of characters and numbers are represented by strings of electrical impulses (Sumner[4]) and the ultimate constraint on computer operating speeds is the time required to transfer these impulses between the components of the processor. The Ferranti *Mercury* (METEOR) installed in 1958 was a first-generation machine based on thermionic valves which were physically large and well separated to disperse the generated heat. The English Electric-Leo KDF9 (COMET) installed in 1965 was a second-generation machine employing closely packed transistors with low power consumption and achieved operating speeds about 10 times that of METEOR. The IBM 360/195 is a third-generation machine based on solid logic technology which achieves a very high packing density by means of layers of miniature printed circuits mounted one on top of the other. It is one of the fastest third-generation general-purpose machines available commercially and is 50 to 100 times faster than COMET. A comparison of the three systems is given in the Appendix.

All modern general-purpose digital computer systems include the following :
  (a) Central processing unit, where the instructions which make up a program are carried out.
  (b) Main storage, where programs and data reside while the former are executed.
  (c) Input devices, such as paper-tape or card readers, for entering programs and data, and output devices, such as line printers, for printing results.
In addition most systems have one or more types of backing store, where programs and data may be stored on-line to the computer ready for transfer to main store and program execution. Backing stores, although slower than

the main store, are much faster than input/output devices and therefore contribute greatly to the overall through-put of work.

Although computing speeds are very dependent on central processor design, the operating speeds of the early computers were constrained by the speeds of the devices used to input programs and data because programs were submitted serially and each one ran to completion before the next was submitted. Nowadays most medium-to-large systems, including most second-generation machines, use a control program (variously called 'operating system', 'supervisor' or 'director') which ensures that other work is started if the program currently being executed has to wait for any reason. This philosophy has been extended to the hardware design in the latest machines. Special stored-program computers (IBM 'channels') are used to connect the input and output devices to the main computer. When input or output is required, the main computer 'instructs' the appropriate channel to undertake the work and the main processor is halted from its main task of computing only long enough to start or stop the channel. Once started the channel completes the data transfer unaided by the main computer.

The control program or operating system also includes a number of facilities such as system 'readers', 'writers' and job 'initiators' which can be stopped and started at will by the operator in charge at the console. Readers and writers control respectively the inflow from devices such as card readers and paper-tape readers to on-line discs and the outflow from discs to line printers or microfilm devices. Initiators may be started for each class of job defined for the system or for several classes to be selected in the order defined by the operator when the initiator is itself selected. Initiators allow the operator to create a mix of work which makes maximum use of all the facilities on the system or to ensure that work which has priority or is time-critical takes precedence when required.

The 360/195 gains much of its speed from a feature known as a high-speed buffer which is linked through a control unit to the main storage and the elements which undertake the computation. The buffer operates at a much higher speed than main storage and blocks of programs (about 20 instructions) or data are copied from main store as the program is executed. Most parts of a program and the related data are required in sequence and hence on almost all occasions the next instruction is waiting with its related data in the buffer and can be transferred very rapidly to the appropriate part of the central processing element (see Figure 1). A 'fetch' of the next block of instructions takes about 20 times as long as a transfer from the buffer but is required only when the next instruction to be obeyed (normally the next in sequence) is not already in the buffer, i.e. when all the immediately usable instructions already stored in the buffer have been obeyed.

The central processing element includes several parts, each of which executes a certain type of instruction, and all parts can operate concurrently with each other. Also, most instructions involve several actions in sequence but the next instruction can be analysed and started before its predecessor is completed.

During 1971 IBM announced a new series of peripherals including new magnetic tapes, discs and alphanumeric cathode-ray-tube peripherals suitable for the 360/195, but these were not available when the new system was

installed in December 1971 and the initial configuration included older types on hire until the new devices became available. The installation is now complete and is shown diagrammatically in Figure 1.

Most peripherals are duplicated on separate channels and automatic two-channel switches are provided for the disc storage devices so that data can be read from or written to discs through the alternative channel if the normal channel is not available. The fixed-head disc, which is a very fast storage device of particular importance for operational numerical forecasting, is not duplicated because of its high cost, but alternative forecast programs have been developed which rely on the moving-head disc drives operating at about half the speed of the fixed-head device.

Five other types of device also deserve special mention. Two KDF9 magnetic-tape drives have been attached through special hardware, thus providing the means of transferring data to and from COMET and also the capacity to read any of the several thousand KDF9 magnetic tapes written during the lifetime of COMET.

The two IBM 2250 graphics display units consist of a cathode-ray tube for the display of characters, numerals and curved or straight lines. Each is equipped with a light-pen (see Plate XIII), alphanumeric keyboard and function keyboard. Programs, which are activated by the function keys, are under development to display data, plot diagrams, including tephigrams, and plot synoptic data to a variety of scales and a selection of areas on a map background. Options are selected by means of the light-pen. One display unit is installed in the Central Forecasting Office (CFO) for experiments on time-critical applications.

The Calcomp 1670 computer output on microfilm (COM) system may be operated off-line, using a 9-track magnetic tape, or on-line to the 360/195. It is a very high-speed incremental plotter which displays data on a very high-resolution $4\frac{1}{2}$-inch cathode-ray tube with an addressable matrix of 16 384 points in the x and y directions, but only $\frac{1}{4}$ of the points can be resolved. There are facilities to superimpose backgrounds, such as coastlines, optically by means of a forms projector — alternatively backgrounds may be produced by program. It takes only about 5 seconds to plot and record on film a British Isles surface chart or to draw the isobars, but about 10 minutes are required to develop film and to produce the first print (14·5 × magnification) of a series by means of a Xerox printer in CFO.

Six IBM 2741 typewriter terminals are attached to the system, five in various branches in the headquarters main building and one at a remote site by means of a telephone line; a second remote unit will be installed at the Meteorological Research Flight, Farnborough. The terminals are similar to a standard electric typewriter and operate under a program known as Conversational Remote Job Entry (CRJE). They are used primarily to create and edit stored programs and data, but programs can be started from the terminals and output routed to the high-speed printers in the computer room or, if the amount is small, the user can receive it on his own slow-speed typewriter. Four cathode-ray-tube alphanumeric terminals with a supporting line printer are being installed in a special area near the computer room for use by all branches and will operate under CRJE, providing much the same facilities as the typewriter terminals.
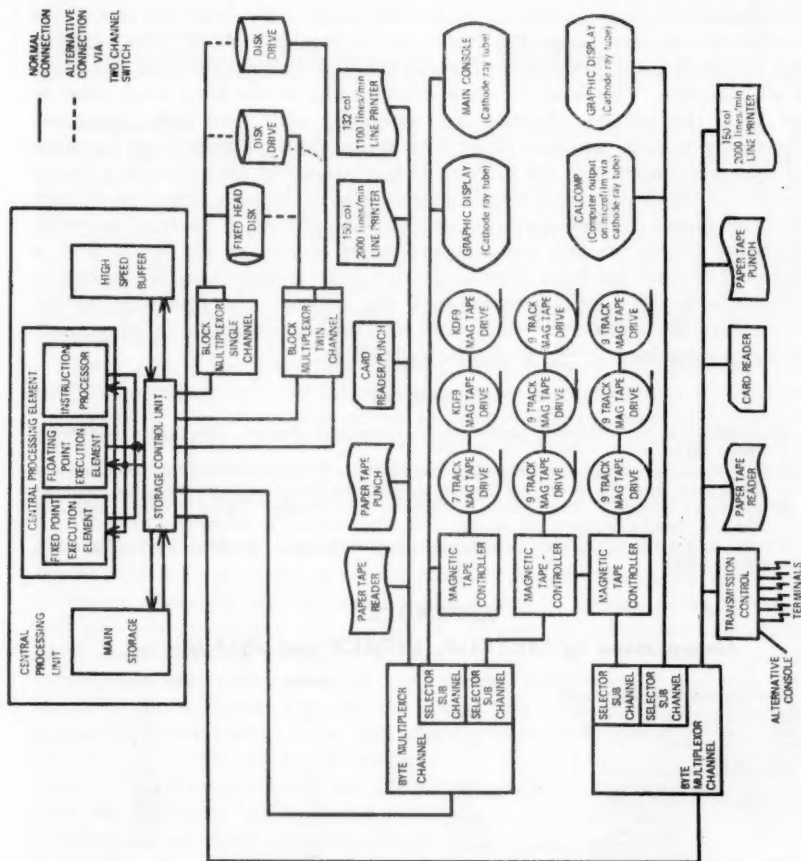
FIGURE I—METEOROLOGICAL OFFICE IBM 360/195 COMPUTER SYSTEM

Concluding remarks. The planning and implementation of the new system demanded sustained efforts not only from several branches of the Meteorological Office but also from other government departments, such as the Department of the Environment, in providing the new accommodation with its many ancillary services, and the computer branches of the Ministry of Defence, Civil Service Department and Her Majesty's Stationery Office, in the planning, selection and procurement of the computer equipment. It was no small achievement on the part of everyone and of IBM to complete the installation within 3 weeks of the planned date. Now, less than 12 months from hand-over, the computing laboratory is handling about 1200 jobs per week for operational forecasting purposes and about 2500 other jobs per week for all branches. This is in no small measure due to the hard work done in Met O 12 by systems planning and operating staff who had almost no opportunity to gain practical experience before the equipment was installed and who were faced with the difficult task of absorbing immediately a heavy work load from Croydon and Poughkeepsie while, at the same time, introducing and developing a suitable operating system. The 360/195 is the most powerful computing facility serving any meteorological service in the world and a great deal of work has been done in the first year of operation. Nevertheless, further efforts will continue to improve the software and operating system to cope with the continually rising work load and consideration is being given already to some increase in the hardware facilities.

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APPENDIX

Comparison of METEOR, COMET and IBM 360/195

(a) Operating speeds (microseconds)	METEOR	COMET	IBM 360/195
Basic machine cycle	60	6	0·05
Access to high-speed buffer store			0·16
Access to main store	120	7	0·81
Addition and			
subtraction — fixed point		1	0·05
— floating point	180	10	0·11
Multiplication — fixed point		15	0·49
— floating point	300	17	0·16
Division — fixed point	3800	37	1·94
— floating point	3800	37	0·54

(b) Major storage capacities (1024 bytes)	METEOR	COMET	IBM 360/195
High-speed buffer			32
Main store	5	144	1 024
Magnetic drum or fixed-head disc	80	240	11 470
Disc			1 170 000

(c) Input/output speeds	No.	Speed	No.	Speed	No.	Speed
Magnetic-tape units			6	40 000 bytes/s	6	120 000 bytes/s
Paper-tape readers	1	300 ch/s	3	1000 ch/s	2	500–1000 ch/s
Paper-tape punches	1	33 ch/s	3	110 ch/s	2	120 ch/s
Card readers			1	600 cards/min	2	1000 cards/min
Card punches					1	300 cards/min
Line printers	1	150 lines/min	1	1000 lines/min	2	2000 lines/min
					1	1000 lines/min

ch = characters

FORECASTING SEASONAL RAINFALL AND TEMPERATURE FOR ENGLAND AND WALES IN SPRING AND AUTUMN FROM ANOMALOUS ATMOSPHERIC CIRCULATION OVER THE NORTHERN HEMISPHERE

By R. MURRAY

Summary. Monthly mean pressure data over the northern hemisphere for nearly 100 years are analysed and simple indices of anomalous circulations in the three months of winter and summer are derived and related to seasonal rainfall and mean temperature over England and Wales in spring and autumn respectively. The prediction rules can be applied in an objective manner. Except in a minority of cases, very useful seasonal forecasts can generally be made.

Introduction. The long series of monthly mean pressure data for the northern hemisphere (1873 to 1969) on magnetic tape have been analysed in searching for possible circulation parameters in key areas of the hemisphere during the three months preceding 'wet' or 'dry' and 'cold' or 'warm' springs and autumns. In this context the terciles of seasonal rainfall over England and Wales and the quintiles of mean temperature over central England are employed. For the detailed procedure and data references two recent papers by Murray[1,2] should be consulted. However, the method may be briefly outlined by an example.

Figure 1(a) is the composite monthly mean pressure anomaly (PA) map for July preceding very cold (quintile 1) autumns in central England, obtained by averaging the PA in each of the 18 Julys which preceded autumns with mean seasonal temperature $<9.1\,°C$ in central England. Similarly Figure 1(b) shows the composite map for July preceding very warm autumns (based on 20 cases each with autumn mean temperature $>10.4\,°C$). Areas where the PA is significantly different from zero at the 5 per cent level of significance are shown as broken lines in these figures. Figure 1(a) is broadly like Figure 1(b) with the signs of the anomalies reversed. Composite maps such as Figure 1 suggest that anomalous circulation in certain areas, generally indicated by significant PA, might be related to subsequent circulation developments leading to cold or warm autumns. The PA at selected points, usually near the centre of areas suggested as significant on the composite maps (or the difference between the PA at two points when this procedure appeared more relevant) were computed for each winter (or summer) month and related to the subsequent spring (or autumn) mean temperature. The ranked PA were examined to see whether they showed worthwhile association with the following spring (or autumn) mean temperature, and classified provided the following objective criteria were satisfied :

(a) The class must contain at least 15 years.

(b) If both ends of the distribution of ranked pressure data appear to have an association with autumn temperature then for each class $SS \geqslant 1.2$, where SS is the Sutcliffe Score (see Murray[1]).

(c) If only one end of the distribution of ranked pressure data appears to have an association with autumn temperature then $SS \geqslant 1.4$.

(d) The pressure class was taken so that the critical pressure anomaly boundary was a whole number (e.g. $PA > 3.0$ mb) provided also that (a) and either (b) or (c) were satisfied.
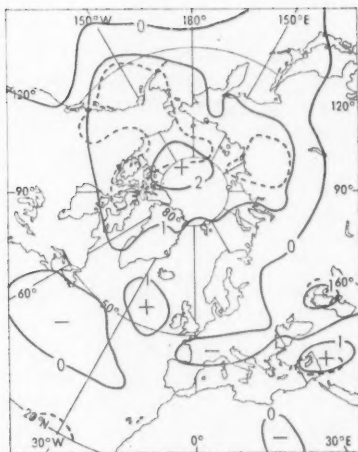
FIGURE 1(a)—MEAN PRESSURE ANOM-
ALY PATTERN IN JULY PRECEDING
VERY COLD (QUINTILE 1) AUTUMNS
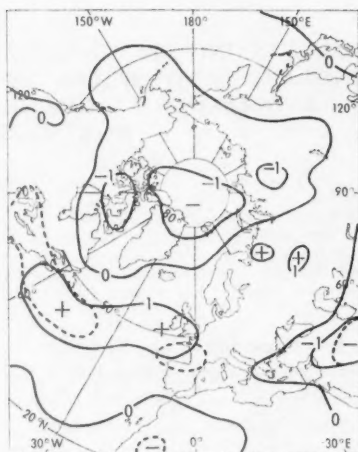OVER CENTRAL ENGLAND.

FIGURE 1(b)—MEAN PRESSURE ANOM-
ALY PATTERN IN JULY PRECEDING
VERY WARM (QUINTILE 5) AUTUMNS
OVER CENTRAL ENGLAND

Pressure anomalies (1-mb intervals) from 1873–1968 average. Broken lines enclose areas
where anomalies are significantly different from zero at 5 per cent level according to *t*-test.

Whenever the PA (or PA differences) were derived for nearby places and
obviously represented the same anomalous features of the circulation, one was
generally selected as representative.

The same procedure was employed to obtain the basic rainfall predictors
except that terciles and upper and lower ten-percentiles of rainfall were
used instead of quintiles.

Forecasting spring rainfall. Table I contains basic information on
simple indices of anomalous circulation in December, January and February
associated with dry or wet springs to follow.

The basic predictors in Table I cannot all be satisfied in a particular
year, but often a preponderance of predictors of either dry or wet springs
is in evidence. A simple discriminant procedure was adopted in the two
recent papers by Murray.[1,2] Equal weight was given to each of the basic
predictors in Table I; whenever the critical anomaly criteria are satisfied
the differences between the number of rules predicting dry and the number
predicting wet were related to the rainfall terciles of the following springs.
Different weights could of course be given to different basic predictors in
different months, but the simplest type of assumptions have in fact been
made and the results shown in Table II appear to be satisfactory.

Table II shows that rather weak indications of spring rainfall are in
evidence from December data. More useful predictions are likely to be
available at the end of January, shown under (b) and (d). Finally when

PLATE I—THE PRIME MINISTER, THE RT. HON. EDWARD HEATH, M.B.E., M.P., SIGNING THE VISITORS' BOOK ON ARRIVAL AT THE METEOROLOGICAL OFFICE, BRACKNELL, ON THE OCCASION OF THE OPENING OF THE NEW RICHARDSON WING ON 6 OCTOBER 1972

The Director-General, Dr B. J. Mason, F.R.S., is on the left.

PLATE II—RICHARDSON WING OF THE METEOROLOGICAL OFFICE HEADQUARTERS, BRACKNELL, SEPTEMBER 1972

PLATE III— THE PRIME MINISTER UNVEILING THE PLAQUE IN THE RICHARDSON WING

VISIT of THE PRIME MINISTER
THE RT. HON. EDWARD HEATH MBE., MP.

for the opening of the

RICHARDSON WING

6th October 1972

Edward Heath

PLATE IV—THE ENTRY IN THE VISITORS' BOOK

This plaque
commemorates
the opening of
the
RICHARDSON WING
by the
Prime Minister
The Rt.Hon.
EDWARD HEATH
MBE·MP
on
6th October 1972
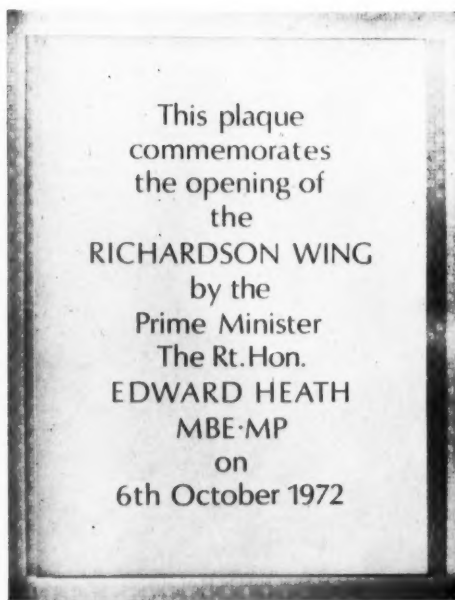
PLATE V—CLOSE-UP OF THE PLAQUE

PLATE VI—PORTRAIT IN GLASS OF L. F. RICHARDSON, D.SC., F.R.S.

The portrait is set in the wall of the entrance hall to the new wing.

PLATE VII—THE PRIME MINISTER EXAMINING THE PRESENTATION
COPY OF *Meteorology for mariners*

The Director-General is on the left.

16 October, 1972

My Dear Director-General

It was a great pleasure for me to be able to
visit Bracknell on Friday, and to open the new
Richardson wing.   I was much impressed by the work
of the Meteorological Office under your direction
and the facilities which are now available to it to
carry out that work, and I should like to send to
you and to all concerned my thanks for an interesting
visit and my good wishes (not entirely unselfish) for
a continuing steady improvement in the accuracy of
your forecasts.

I should also like to thank you and your staff
for presenting me with a copy of <u>Meteorology for
Mariners</u>; I hope that this will enable at least one
of your customers to make even better use of your
forecasts than he already does.

With best wishes,
Yours sincerely,

Director-General of the Meteorological Office.

PLATE VIII—LETTER OF APPRECIATION FROM THE PRIME MINISTER TO THE
DIRECTOR-GENERAL

PLATE IX—PART OF THE MANUAL TELECOMMUNICATIONS CENTRE IN THE RICHARDSON WING
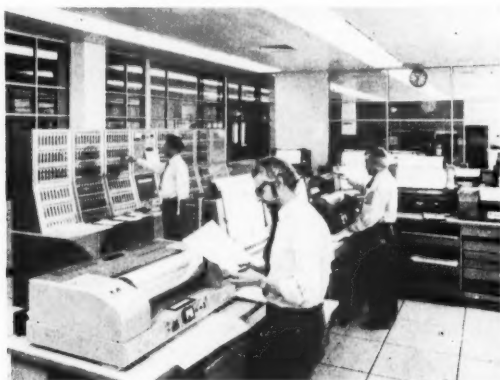

PLATE X—PART OF THE FACSIMILE ROOM

In the foreground are two facsimile transmitters and behind to the left are the switching panels whereby any transmission or reception can be relayed to any outgoing channel.

PLATE XI—CENTRAL FORECASTING OFFICE—THE UPPER-AIR SECTION

PLATE XII—THE COMPUTER ROOM

The seated staff member farthest from the camera is controlling the machine from the main console. Plate XIII is a close-up. The two staff members in the right foreground are controlling magnetic-tape units. The one in the centre foreground is manipulating a paper-tape reader and the one towards the left is attending one of the three line-printers.

PLATE XIII—MAIN OPERATING CONSOLE WITH CONTROLLER USING LIGHT-PEN

TABLE I—PRESSURE ANOMALIES AND PRESSURE ANOMALY DIFFERENCES AT KEY
AREAS IN DECEMBER, JANUARY AND FEBRUARY RELATED TO SPRING RAINFALL
IN ENGLAND AND WALES

Rule No.	Pressure anomaly (PA) or difference	Normal	Critical anomaly	Spring rainfall (terciles)			Bias
		millibars		1	2	3	
(a) December							
1	PA(60 60E)	1019·3	< − 5	2	7	13	wet
2	PA(40 10)	1020·2	> 4	3	3	11	wet
3	PA(45 10) − PA(65 20)	1017·5 − 999·8	> 6	6	8	17	wet
(b) January							
4	PA(60 20E)	1012·4	> 5	4		14	wet
5	PA(60 70E) − PA(60 20E)	1020·8 − 1012·4	> 5	14	6	5	dry
6	PA(70 40)	1004·8	< − 7	3	5	10	wet
7	PA(70 40) − PA(60 10E)	1004·8 − 1011·6	< −10	3	4	9	wet
8	PA(35 130)	1020·3	> 3	1	7	7	wet
9	PA(65 140)	1018·0	> 7	2	4	9	wet
10	PA(65 140) − PA(60 50)	1018·0 − 998·9	< − 8	10	2	4	dry
11	PA(65 140) − PA(60 50)	1018·0 − 998·9	> 2	6	11	17	wet
(c) February							
12	PA(80 20E)	1009·1	> 7	10	2	3	dry
13	PA(45 60)	1011·8	> 4	11	8	3	dry
14	PA(60 30)	1001·5	< −10	10	5	3	dry
15	PA(80 20E) − PA(60 30)	1009·1 − 1001·5	< − 5	4	10	17	wet
16	PA(80 20E) − PA(60 30)	1009·1 − 1001·5	> 6	11	9	2	dry
17	PA(55 20E)	1015·0	> 4	15	5	5	dry
18	PA(30 70)	1019·5	< 0	7	11	21	wet
19	PA(60 30) − PA(55 20E)	1001·5 − 1015·0	< − 8	14	10	3	dry
20	PA(60 30) − PA(30 70)	1001·5 − 1019·5	< − 4	15	11	5	dry
21	PA(60 30) − PA(30 70)	1001·5 − 1019·5	> 12	4	3	9	wet
22	PA(60 30) − PA(40 00)	1001·5 − 1018·4	< − 9	15	10	4	dry

Normal monthly pressure or pressure difference refers to the period 1873 to 1968.

Note : Spring rainfall terciles, based on period 1874 to 1963, are : $R_1 < 160$ mm;
$160 < R_2 < 193$ mm; $R_3 > 193$ mm.

TABLE II—LAG ASSOCIATIONS BETWEEN VARIOUS COMBINATIONS OF RULES BASED
ON MONTHLY PRESSURE ANOMALIES IN DECEMBER, JANUARY AND FEBRUARY OVER
THE NORTHERN HEMISPHERE AND SPRING RAINFALL OVER ENGLAND AND WALES

Period	Predictor	Spring rainfall (terciles)			Totals	SS
		1	2	3		
(a) December	$N_w > 1$	7	12	27	46	1·7
	$N_w = 0$	25	16	9	50	1·2
(b) January	$N_d − N_w > 1$	14	4	3	21	2·1
	$N_d − N_w < −2$	5	10	19	34	1·6
(c) February	$N_d − N_w > 2$	23	13	3	39	2·0
	$N_d − N_w < −1$	5	10	24	39	1·9
(d) December	*$N_d − N_w > 0$	22	7	4	33	2·1
+January	$N_d − N_w < −2$	6	16	25	47	1·6
(e) December						
+January	1. $N_d − N_w > 2$	22	9	1	32	2·6
+February	2. $N_d − N_w < −2$	1	11	28	40	2·7

* This contains 9 years when $N_d = N_w = 0$.

N_d and N_w are the number of individual predictors (see Table I) which indicate dry (R_1)
and wet (R_3) springs respectively. SS is the mean Sutcliffe Score. Tercile boundaries are
given in Table I.

the anomalous circulation in February is known (usually on the last day of February) the two operational rules at (e), based on the circulation in the three winter months, give strong indications of dry *(R₁)* or wet *(R₃)* springs on some 72 per cent of occasions. If the latter rules are not applicable then the rules at (c) or (d) should be examined, and if none applies no prediction can be issued by this method. However, in the vast majority of years some positive prediction should be possible.

The long-period mean surface pressure map for spring (i.e. March, April and May) is shown in Figure 2. In general, individual springs have mean
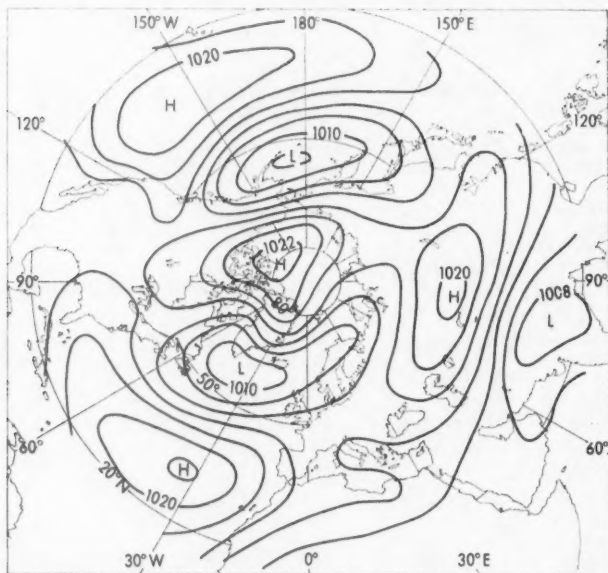

FIGURE 2—MEAN SURFACE PRESSURE IN SPRING, PERIOD 1873 TO 1968

pressure distributions which are different to a greater or less extent from the seasonal pattern in Figure 2. A composite of the mean pressure anomalies associated with the 32 springs in which the winter pre-conditions for dry springs given under (e)1 of Table II (i.e. $N_d - N_w \geqslant 2$) were satisfied, is shown in Figure 3. In this composite map the mean pressure in spring is significantly (at the 5 per cent level) above average over the British Isles and significantly below the seasonal average from the Russian Arctic to Greenland. A composite map (not shown) for the 40 cases which satisfied the criterion $N_d - N_w \leqslant -2$ (i.e. (e)2 of Table II) for wet springs is characterized by mean pressure which is significantly below average over the British Isles; mean pressure is above average in the Arctic, although only significantly so near southern Greenland. The composite pattern in the latter case is similar to that shown in Figure 3 if the signs of the anomalies are reversed.

Forecasting spring temperature. Table III contains the basic information from anomalous circulation in the winter months associated with cold or warm springs.

TABLE III—PRESSURE ANOMALIES AND PRESSURE ANOMALY DIFFERENCES AT KEY AREAS IN DECEMBER, JANUARY AND FEBRUARY RELATED TO SPRING MEAN TEMPERATURE IN CENTRAL ENGLAND

Rule No.	Pressure anomaly (PA) or difference	Normal	Critical anomaly	Spring temperature (quintiles)					Bias
		millibars		1	2	3	4	5	
(a) December									
1	PA(60 40)	998·5	> 7	8	2	5	2	1	cold
2	PA(60 40) − PA(55 30E)	998·5 − 1016·5	< −12	1	2	5	4	6	warm
3	PA(60 40) − PA(50 90E)	998·5 − 1033·1	< − 5	1	5	3	7	9	warm
4	PA(60 40) − PA(50 90E)	998·5 − 1033·1	> 6	9	1	2	3	0	cold
5	PA(80 140E) − PA(65 40)	1019·6 − 1000·4	< − 5	12	1	6	5	0	cold
6	PA(70 120E)	1022·3	> 4	1	3	2	8	4	warm
7	PA(35 50E)	1020·7	< − 1	3	3	8	14	4	warm
(b) January									
8	PA(40 60)	1015·4	< − 3	3	1	6	3	11	warm
(c) February									
9	PA(75 20)	1010·7	< − 5	1	1	5	10	9	warm
10	PA(45 10E)	1016·9	< − 5	8	4	5	3	0	cold
11	PA(45 10E)	1016·9	> 3	4	1	5	11	10	warm
12	PA(75 120)	1021·7	> 4	3	10	5	3	1	cold
13	PA(35 30) − PA(55 00)	1020·3 − 1013·3	> 11	2	8	3	1	1	cold
14	PA(55 160) − PA(45 130)	1003·7 − 1015·8	< − 1	3	4	8	12	14	warm
15	PA(45 10E) − PA(55 50)	1016·9 − 1003·9	< − 8	6	6	4	2	1	cold
16	PA(45 10E) − PA(55 50)	1016·9 − 1003·9	> 7	3	0	1	10	6	warm
17	PA(45 10E) − PA(40 50E)	1016·9 − 1020·2	< − 5	9	8	5	1	0	cold
18	PA(45 10E) − PA(40 50E)	1016·9 − 1020·2	> 5	2	2	3	9	8	warm
19	PA(45 10E) − PA(75 160)	1016·9 − 1022·7	< − 8	6	5	4	1	1	cold
20	PA(45 10E) − PA(75 160)	1016·9 − 1022·7	> 6	3	0	5	8	8	warm
21	PA(45 10E) − PA(45 30)	1016·9 − 1012·8	< − 5	9	8	8	0	1	cold
22	PA(45 10E) − PA(45 30)	1016·9 − 1012·8	> 7	2	1	2	5	7	warm

Normal monthly pressure or pressure difference refers to the period 1873 to 1968.

Note : Spring temperature quintiles, based on period 1874 to 1963, are : $T_1 < 7·5$; $7·5 \leqslant T_2 < 8·1$; $8·1 \leqslant T_3 < 8·4$; $8·4 \leqslant T_4 < 8·9$ $T_5 \geqslant 8·9°C$.

The basic predictors which were satisfied in individual years were combined in the same way as for rainfall and the predictive rules for spring temperature contained in Table IV were obtained.

TABLE IV—LAG ASSOCIATIONS BETWEEN VARIOUS COMBINATIONS OF RULES BASED ON MONTHLY PRESSURE ANOMALIES IN DECEMBER, JANUARY AND FEBRUARY OVER THE NORTHERN HEMISPHERE AND SPRING TEMPERATURE IN CENTRAL ENGLAND

Period	Predictor	Spring temperature (quintiles)					Totals	SS
		1	2	3	4	5		
(a) December	$N_c − N_w \geqslant 1$	11	2	5	2	1	21	1·9
	$N_c − N_w \leqslant −2$	0	2	4	9	7	22	2·0
(b) December +January	$N_c − N_w \geqslant 1$	11	1	3	2	1	18	2·1
	$N_c − N_w \leqslant −2$	1	3	5	10	13	32	1·9
(c) February	$N_c − N_w \geqslant 2$	9	11	7	1	0	29	2·0
	$N_c − N_w \leqslant −1$	4	1	10	16	17	48	1·7
	$(< −4)$	(1)	(0)	(2)	(9)	(8)	(20)	(2·1)
(d) December +January +February	1. $N_c − N_w \geqslant 2$	11	10	4	1	0	26	2·3
	*2. $N_c − N_w = 1$ or 0 or − 1	4	3	10	6	2	25	1·1
	3. $N_c − N_w \leqslant −2$	3	2	7	15	17	44	1·8
	$(< −4)$	(1)	(1)	(3)	(10)	(10)	(25)	(2·1)

* Neglecting one case when $N_c = N_w = 0$.

N_c and N_w are the number of individual predictors (see Table III) which indicate very cold or cold (T_1 or T_2) and warm or very warm (T_4 or T_5) springs respectively. SS is the mean Sutcliffe Score. Quintile boundaries are given in Table III.

Note : For a predictor value in brackets, the quintile distribution is shown in brackets.

It is clear from Table IV that quite useful indications of the probability of cold or warm springs are available at the end of December on about 45 per cent of years. January adds little extra information. However, the overall predictors based on the three winter months are likely to be applicable

and useful on virtually all occasions. The rules (d)1 and (d)3 are particularly strong and they will probably be applicable on average in three out of four years. The figures in brackets refer to the cases when the more stringent pre-condition is satisfied. The final forecast should be based on rules (d)1, (d)2 and (d)3. If the pre-condition which is satisfied is (d)1 predict T_1 or T_2, if (d)2 predict T_3, if (d)3 predict T_4 or T_5. The choice between T_1 and T_2 or between T_4 and T_5 will generally depend on other considerations; in any case the temperature forecasts would be regarded as satisfactory even if the error were one quintile. In using (d)2 the prediction should normally be T_3, but it may be T_2 or T_4 if the (c) rules for February or other considerations (e.g. sea temperatures) suggest a slight bias.

It is of interest to see in Figure 4 the composite mean pressure anomaly map for the 26 springs in which the criterion $N_c - N_w \geqslant 2$ for predicting a cold spring (given under (d) of Table IV) was satisfied. The main features
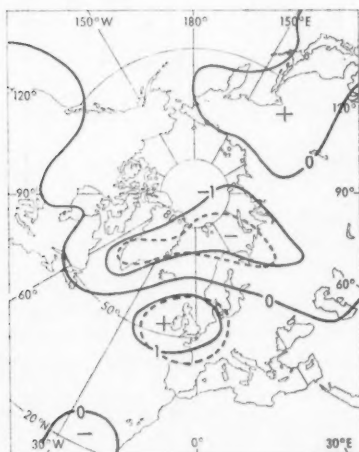

FIGURE 3—COMPOSITE MEAN PRESSURE ANOMALY PATTERN IN SPRINGS FOLLOWING WINTERS SATISFYING THE RAINFALL PREDICTOR $N_d - N_w \geqslant 2$ GIVEN IN TABLE II(e)1
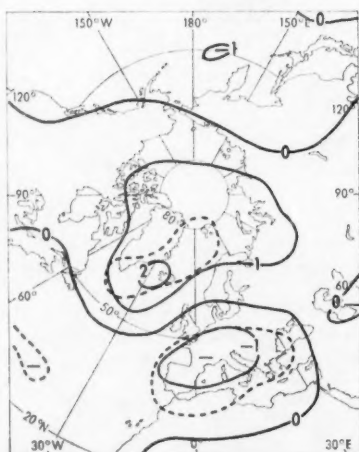
See notes under Figure 1.

FIGURE 4—COMPOSITE MEAN PRESSURE ANOMALY PATTERN IN SPRINGS FOLLOWING WINTERS SATISFYING THE TEMPERATURE PREDICTOR $N_c - N_w \geqslant 2$ GIVEN IN TABLE IV(d)1

of Figure 4 are the extensive areas with below-average mean pressure over Europe and the Mediterranean and above-average mean pressure over Iceland, Greenland and the Arctic; in these two regions mean seasonal pressure is significantly different from average over large areas centred on France and on the Denmark Strait. Evidently blocking on an enormous scale is shown in Figure 4. Nor is it surprising that most of the springs were cold over central England in view of the north-east anomaly of flow indicated in Figure 4. The criterion for warm springs, $N_c - N_w \leqslant -2$, given as (d)3 in Table IV, was satisfied in 44 years; the composite pressure anomaly map

(not shown) suggested anomalously strong westerly flow in the Atlantic sector, with the pressure near Iceland being significantly below average and the Azores anticyclone being stronger than usual.

Forecasting autumn rainfall. The basic predictions in June, July and August and the derived operational rules for forecasting autumn rainfall are listed in Tables V and VI respectively. No dry or wet predictor satisfying the pre-conditions laid down in the Introduction was found for July, but there were two related basic predictors which suggested average rainfall (see Table V).

TABLE V—PRESSURE ANOMALIES AND PRESSURE ANOMALY DIFFERENCES AT KEY AREAS IN JUNE, JULY AND AUGUST RELATED TO AUTUMN RAINFALL IN ENGLAND AND WALES

Rule No.	Pressure anomaly (PA) or difference	Normal	Critical anomaly	Autumn rainfall (terciles)			Bias
		millibars		1	2	3	
(a) June							
1	PA(45 80)	1014·3	< −1	4	10	14	wet
2	PA(55 80)	1012·4	> 2	9	7	2	dry
(b) July							
3	PA(40 40E) −PA(65 20E)	1008·1 − 1010·4	> 2	4	15	4	average
4	PA(40 40E)	1008·1	> 1	5	16	4	average
(c) August							
5	PA(80 180)	1015·7	> 4	9	6	2	dry
6	PA(80 180) −PA(45 160E)	1015·7 − 1013·0	> 5	10	4	2	dry
7	PA(65 110E)	1010·3	> 2	11	7	1	dry
8	PA(65 110E) −PA(55 50E)	1010·3 − 1011·8	< −3	5	6	15	wet
9	PA(65 110E) −PA(55 50E)	1010·3 − 1011·8	> 0	20	17	5	dry
10	PA(55 160) −PA(75 160E)	1012·8 − 1013·6	< −3	12	9	3	dry

Normal monthly pressure or pressure difference refers to the period 1873 to 1968.
Note : Autumn rainfall terciles, based on the period 1874 to 1963, are : $R_1 < 234$ mm; $234 < R_2 < 305$ mm; $R_3 > 305$ mm.

TABLE VI—LAG ASSOCIATIONS BETWEEN VARIOUS COMBINATIONS OF RULES BASED ON MONTHLY PRESSURE ANOMALIES IN JUNE, JULY AND AUGUST OVER THE NORTHERN HEMISPHERE AND AUTUMN RAINFALL OVER ENGLAND AND WALES

Period	Predictor	Autumn rainfall (terciles)			Totals	SS
		1	2	3		
(a) June	$N_w=0, N_d=1$	9	7	2	18	1·5
	$N_d=0, N_w=1$	4	10	14	28	1·4
(b) July	$N_a=2$	1	12	2	15	2·8
(c) August	1. $N_d-N_w>1$	25	19	6	50	1·5
	(>3)	(10)	(6)	(1)	(17)	(2·1)
	*2. $N_d-N_w<0$	8	13	26	47	1·5
(d) June	1. $N_d-N_w>2$	17	9	2	28	2·1
+August	2. $N_d-N_w<-1$	3	9	17	29	1·9

* This includes 22 years with $N_d=N_w=0$.

N_d, N_a and N_w are the number of individual predictors (see Table V) which indicate dry (R_1), average (R_2), and wet (R_3) autumns respectively. SS is the mean Sutcliffe Score. Tercile boundaries are given in Table V.

Note : For a predictor value in brackets, the tercile distribution is shown in brackets.

On less than 50 per cent of occasions some indication of autumn rainfall can probably be given in June. In a small number of years the circulation in July will suggest that an average type of autumn will probably follow.

The August predictors can generally be invoked, but the forecast accuracy is likely to be high only in the more stringent case shown in brackets in (c)1. The operational rule (d) involving June and August should be used unless rule (b), based on the July mean circulation, suggests that the rainfall will be average. If neither rule (b) nor rule (d) is applicable, prediction should be based on rule (c) or on other considerations.

The long-period mean surface pressure map for autumn is given in Figure 5. Wet or dry autumns over England and Wales typically differ from
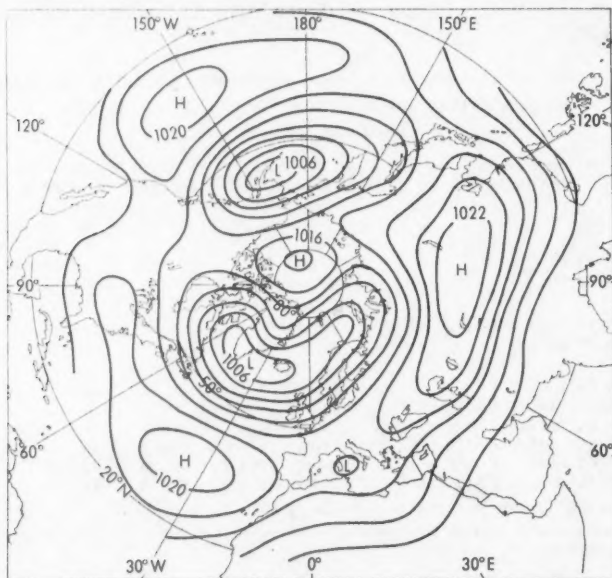
FIGURE 5—MEAN SURFACE PRESSURE IN AUTUMN, PERIOD 1873 TO 1968

Figure 5 and the anomalous circulation can of course be seen by examining seasonal pressure anomalies. The composite autumn pressure anomaly pattern which emerges when the criterion for a wet autumn is satisfied, namely $N_d - N_w \leqslant -1$ in (d)2 of Table VI, is depicted in Figure 6, where the main feature is the below-average mean pressure over the British Isles. The composite map for the dry autumns (not shown) associated with the predictive criterion $N_d - N_w \geqslant 2$ (i.e. (d)1 of Table VI) is roughly similar to Figure 6 with the signs of the anomalies reversed : the main difference is that the mean pressure is significantly above average from Mongolia northwards to the polar region and also over Hudson Bay.

Forecasting autumn temperature. Table VII lists the basic predictors in the summer months and Table VIII summarizes the rules for predicting autumn mean temperature.

Predictions of warm autumns are possible on less than 25 per cent of years at the end of June, as indicated by rule (a) of Table VIII. At the end of July fairly accurate predictions can be made much more often, either from rule (b) or rule (d) of Table VIII. August adds further information so that

TABLE VII—PRESSURE ANOMALIES AND PRESSURE ANOMALY DIFFERENCES AT KEY AREAS IN JUNE, JULY AND AUGUST RELATED TO AUTUMN MEAN TEMPERATURE IN CENTRAL ENGLAND

Rule No.	Pressure anomaly (PA) or difference	Normal	Critical anomaly	Autumn temperature (quintiles)					Bias
		millibars		1	2	3	4	5	
(a) June									
1	PA(45 140E)	1008·8	> 1	0	3	6	3	10	warm
2	PA(40 140)	1021·8	> 3	3	2	0	10	5	warm
3	PA(40 140) − PA(70 140)	1021·8 − 1015·3	> 4	3	2	2	10	4	warm
4	PA(45 50E) − PA(60 20)	1011·0 − 1011·6	> 3	0	4	3	3	7	warm
(b) July									
5	PA(65 100E)	1008·0	> 2	9	3	7	1	2	cold
6	PA(60 150)	1014·2	> 2	11	1	5	3	1	cold
7	PA(45 00)	1017·4	< −1	6	10	6	4	1	cold
8	PA(40 50)	1020·8	< −1	7	9	8	3	2	cold
9	PA(40 50)	1020·8	> 2	1	3	3	3	7	warm
10	PA(70 100) − PA(40 50)	1012·6 − 1020·8	< −3	2	2	4	6	8	warm
11	PA(70 100) − PA(40 50)	1012·6 − 1020·8	> 2	10	7	11	1	2	cold
12	PA(60 40) − PA(40 40)	1010·7 − 1023·2	> 5	4	5	6	0	1	cold
13	PA(35 170) − PA(70 100)	1023·1 − 1012·6	< −3	6	6	5	0	3	cold
14	PA(35 170) − PA(70 100)	1023·1 − 1012·6	> 3	1	5	2	10	8	warm
15	PA(50 00) − PA(65 40)	1016·4 − 1011·0	< −4	5	8	5	3	1	cold
16	PA(35 50E)	1003·0	< −2	2	3	3	5	7	warm
17	PA(35 50E)	1003·0	> 2	3	7	2	2	1	cold
18	PA(45 00) − PA(80 20)	1017·4 − 1014·3	< −4	4	6	5	3	0	cold
19	PA(45 00) − PA(80 20)	1017·4 − 1014·3	> 3	1	1	4	6	6	warm
20	PA(45 80) − PA(70 100)	1014·6 − 1012·6	< −3	7	4	6	0	2	cold
21	PA(45 80) − PA(70 100)	1014·6 − 1012·6	> 2	2	4	1	10	9	warm
(c) August									
22	PA(70 160)	1012·0	< −2	1	4	3	8	11	warm
23	PA(30 00)	1012·1	< −1	2	5	5	8	12	warm
24	PA(30 00)	1012·1	> 0	14	10	9	3	3	cold
25	PA(70 160) − PA(45 150)	1012·0 − 1021·1	< −3	2	3	2	9	10	warm
26	PA(70 160) − PA(45 150)	1012·0 − 1021·1	> 4	6	6	6	0	1	cold
27	PA(40 150)	1023·9	< −1	12	10	10	1	5	cold
28	PA(40 150)	1023·9	> 2	3	3	4	9	9	warm

Normal monthly pressure or pressure difference refers to the period 1873 to 1968.

Note : Autumn mean temperature quintiles, based on period 1874 to 1963, are : $T_1 < 9·1$; $9·1 \leqslant T_2 < 9·7$; $9·7 \leqslant T_3 < 10·1$; $10·1 \leqslant T_4 < 10·5$; $T_5 \geqslant 10·5°C$.

TABLE VIII—LAG ASSOCIATIONS BETWEEN VARIOUS COMBINATIONS OF RULES BASED ON MONTHLY MEAN PRESSURE ANOMALIES IN JUNE, JULY AND AUGUST OVER THE NORTHERN HEMISPHERE AND AUTUMN MEAN TEMPERATURE IN CENTRAL ENGLAND

Period		Predictor	Autumn temperature (quintiles)					Totals	SS
			1	2	3	4	5		
(a) June		$N_c = 0$, $N_w \geqslant 2$	1	2	1	11	7	22	2·0
(b) July		$N_c - N_w \geqslant 4$	10	7	8	0	1	26	1·9
		$N_c - N_w \leqslant -1$	2	4	6	11	16	39	1·8
		(< -2)	(0)	(1)	(3)	(6)	(10)	(20)	(2·5)
(c) August		$N_c = 0$, $N_w \geqslant 2$	0	4	3	10	10	27	1·9
		$N_w = 0$, $N_c \geqslant 1$	13	10	10	1	1	35	1·8
(d) June		$N_c - N_w \geqslant 4$	9	6	7	0	0	22	2·1
+July		$N_c - N_w \leqslant -3$	0	0	3	10	12	25	2·7
(e) June	1.	$N_c - N_w \geqslant 3$	14	9	9	0	1	33	2·1
+July	2.	$N_c - N_w = 2, 1, 0$ or -1	3	6	9	3	4	25	1·0
+August	3.	$N_c - N_w \leqslant -2$	1	4	2	16	16	39	2·1
		(< -6)	(0)	(0)	(1)	(7)	(9)	(17)	(3·0)

N_c and N_w are the number of individual predictors (see Table VII) which indicate cold (T_1 or T_2) or warm (T_4 or T_5) autumns respectively. SS is the mean Sutcliffe Score. Quintile boundaries are given in Table VII.

Note : For a predictor value in brackets, the quintile distribution is shown in brackets.

the operational rules based on the three summer months shown under (e) of Table VIII enable very useful predictions to be made of the mean autumn temperature in central England. Rules (e)1 and (e)3 are clearly more reliable than rule (e)2. When the latter rule applies there is rather weak evidence for predicting T_3 but T_2 or T_4 could be forecast if either rule (c) or rule (d) suggests a bias to the cold or warm side of average temperature. Rule (e)1 strongly indicates that the autumn will not be warm; the best prediction in practice is T_1 or T_2. Rule (e)3 predicts a warm autumn $(T_4$ or $T_5)$; if the more stringent criterion in brackets is satisfied the probability of a warm autumn is extremely high.

The typical anomalous circulation in autumn associated with predictions based on the criterion $N_c-N_w\leqslant-2$ for June, July and August (i.e. (e)3 of Table VIII) is shown in the composite map in Figure 7. The south-west
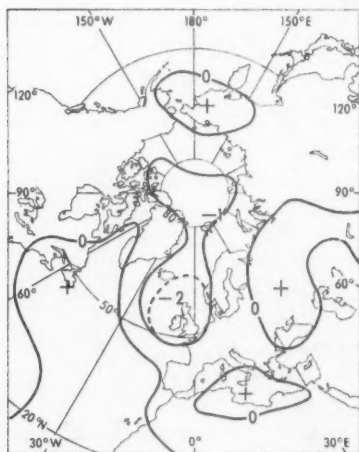
FIGURE 6—COMPOSITE MEAN PRESSURE ANOMALY PATTERN IN AUTUMNS FOLLOWING SUMMERS SATISFYING RAINFALL PREDICTOR $N_d-N_w\leqslant-1$ GIVEN IN TABLE VI(d)2
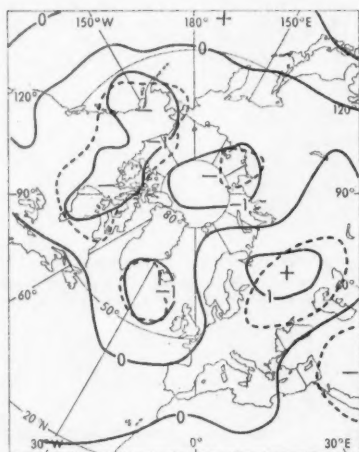
FIGURE 7—COMPOSITE MEAN PRESSURE ANOMALY PATTERN IN AUTUMNS FOLLOWING SUMMERS SATISFYING THE TEMPERATURE PREDICTOR $N_c-N_w\leqslant-2$ GIVEN IN TABLE VIII(e)3

See notes under Figure 1.

anomaly of flow over England is of course characteristic of many warm autumns. The circulation anomalies in Figure 7 are on a very large scale; mean pressure is significantly below average over most of Canada, the north-east Atlantic and near the Siberian Arctic and significantly above average over Russia. In contrast the composite map (not shown) associated with the years in which the predictive criterion $N_c-N_w\geqslant3$ (i.e. (e)1 of Table VIII) is satisfied shows mean pressure significantly above average over Alaska, much of Canada, and the north-east Atlantic but significantly below average in an area north of the Caspian Sea and in the North Pacific south of the Aleutian Islands; the composite map in this case is like Figure 7 with the signs of the anomalies reversed.

Discussion. The qualitative arguments for the use of monthly mean pressure anomaly data over the northern hemisphere in developing objective rules for predicting seasonal rainfall and mean temperature have been given in two recent papers[1,2] and need not be restated here.

The empirical rules in this paper have been derived from data covering nearly 100 years during which time longer-period changes in seasonal temperature and rainfall have taken place, but the writer has not noticed that the overall rules based on the three months before the season in question are significantly different in the accuracy of their predictions in the different epochs. For instance in the decade 1960 to 1969, the spring rainfall rules (e) of Table II and the spring temperature rules (d) of Table IV gave mean Sutcliffe Scores of 3·0 and 2·8 respectively. In the same decade, the autumn rainfall rules (d) of Table VI and the autumn temperature rule (e) of Table VIII gave mean Sutcliffe Scores of 1·8 and 2·2 respectively. In this recent decade there has been a noticeable trend to warm autumns. In fact there were no very cold autumns in central England and only two T_2 (quintile 2) autumns, namely 1962 and 1965. The predictor N_c-N_w was equal to 4 in 1962 and 1 in 1965; rules (d) of Table VIII predicted T_1 or T_2 for the 1962 autumn and T_3 for the 1965 autumn. In the other 8 cases the pre-condition $N_c-N_w \leqslant -2$ ((e) of Table VIII) was satisfied; in other words, warm autumns were indicated and in fact the mean temperatures in these 8 autumns were quintiles 5, 4 and 3 on four, two and two occasions respectively. Thus a recent trend in autumn temperature was satisfactorily handled by the predictive criteria.

The years 1970 to 1972 were not included in the data from which the various rules were derived. In predicting the spring rainfall for 1970 and 1971 the rules in Table II in the individual months were conflicting. In each case the overall rules based on the three months indicated that the seasonal rainfall was unlikely to be tercile 1 or tercile 3. In such cases either tercile 2 (average) or no forecast should be given; in the event both seasons had average rainfall. At the end of February 1972 rule (e)2 in Table II was satisfied and a wet spring was correctly predicted. The autumn rainfall in 1970 was correctly predicted as average on the basis of the rule (b) in Table VI. However, no basic rule was applicable from any of the summer months in 1971, so that no forecast could be given. As regards the temperature forecasts (see Table IV) the spring rule (d)1 was satisfied in 1970 so that a cold spring was predicted and T_2 occurred; in 1971 the rule (d)2 applied, thus an average (T_3) spring was expected and in the event the mean temperature was T_3: in 1972 an average (T_3) spring was expected from rule (d)2 and the mean spring temperature was actually T_4. The autumns of 1970 and 1971 were very warm (T_5); in each case the predictive rule for warm or very warm autumns, given as (e)3 in Table VIII, was satisfied ($N_c-N_w=-9$ in 1970 and $N_c-N_w=-3$ in 1971). Thus in these recent years of independent data the predictive rules have proved very successful.

There is not yet in sight any numerical procedure, based on physical laws, which will allow seasonal weather predictions of practical value to be made. With all its limitations an essentially empirical approach to seasonal forecasting, such as has been presented in this paper and in the two recent papers to which reference has been made, gives useful, practical results. In the

course of time, it is very likely that a marriage between this type of empirical work and physically based numerical researches will produce substantially more reliable seasonal forecasts. In the meantime forecasts of seasonal weather over England and Wales can generally be made with a high expectation of success, although on a minority of occasions forecasts will not be possible or will be seriously in error.

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TROPOSPHERIC WINDS AND THE OCCURRENCE OF RAINFALL NEAR THE EQUATOR

By D. E. PARKER

Summary. Mean winds at tropospheric levels over Gan, Nairobi, and the Seychelles were found for wet days and for dry days up to three days before and after wet days. Mean winds at tropospheric levels over Gan were also found for dry days in general. The most significant finding was a reduction in easterly flow in the vertical-shear zone beneath the northern summer upper-tropospheric easterly jet over Gan on wet days in comparison with the flow on surrounding dry days or with the overall mean flow.

Introduction. The interaction between tropical convection and the surrounding large-scale flow is an important element in the dynamics of the tropical atmosphere. An indirect method of studying this interaction is to look for statistical relationships between tropospheric winds and occurrence of rainfall in the tropics. The relationship between upper-tropospheric winds and rainfall during the south-west monsoon over India has in fact been investigated by George,[1] who explained many features in terms of vorticity advection associated with variations in the upper-tropospheric easterly jet. The present work is concerned with winds and rainfall near the equator over the western half of the Indian Ocean and over East Africa, but vorticity considerations are beyond the scope of the work because upper-wind data were readily available from only three stations.

Procedure. The stations used were Gan (00° 41′S, 73° 09′E), Port Victoria (04° 37′S, 55° 27′E) on Mahé Island in the Seychelles group, and Nairobi (01° 18′S, 36° 45′E). The stations were treated separately. Most of the calculations were for Gan where orography plays a very small part.

Days were classified as either dry or wet, the criterion for wet days being either ≥ 1 mm or ≥ 4 mm total rainfall.

Mean zonal and meridional wind components at each level were calculated for Gan for dry days in general $(U_d$ and $V_d)$, and for each station for wet days $(U_w$ and $V_w)$ and for dry days up to three days before and after wet days $(U_{w+j}$ and V_{w+j}, $j = -3$, -2, -1, 1, 2, 3 days). For this purpose it was necessary to allow for occasions when wet days were separated by five dry days or less. For these occasions dry days were used with the nearest wet day, those dry days midway between two wet days being excluded. Any dry days up to three days before the start of the first year of an analysis or up to three days after the end of the last year were not used.

Results. Table I gives U_w, U_d and $U_w - U_d$ at each level over Gan for the mid-season months, using data for 1960 to 1964 and taking the 1-mm criterion for wet days. There were consistent slight excesses of westerly component at the surface and 900 mb, and consistent deficits of easterly component between 400 mb and 200 mb, on wet days. The latter effect was most marked in July when the upper-tropospheric easterlies were strongest. There were no consistent patterns in $V_w - V_d$.

Figure 1 compares U_{w+j} with U_w and the all-days mean U for Gan, using the 1-mm criterion. The most notable feature was at 200 mb and 250 mb during May to October (Figure 1(b)) when U_{w+j} was less than U_w, by an amount which increased with increasing $|j|$ to become about 10 kt. This characteristic was not repeated to a marked extent during November to April (Figure 1(c)). However, during this season there was a general tendency for $U_{w+k} > U_{w+l}$, where $k > l$, in the lower and middle troposphere, while at 150 mb $U_{w+k} < U_{w+l}$ in no uncertain fashion (Figure 1(c)). The major features of the complete period 1960 to 1964 (Figure 1(a)) were also present in 1967. However, the raised values in the region of 800 mb to 500 mb after wet days (Figure 1(a)) were virtually missing in 1966.

Changing the rainfall criterion to 4 mm made little difference to the results.

There appeared to be no systematic features in $U_{w+j} - U_w$ at Nairobi or at Port Victoria. Wind data for Port Victoria were virtually confined to 1964.

In 1964 the mean meridional winds at 900, 850 and 800 mb over Port Victoria were about 3 kt more northerly on wet days (using either criterion) than on the relevant surrounding dry days up to $j = \pm 3$. The opposite effect held, with a magnitude of nearly 2 kt, at 700 mb over Nairobi using the 4-mm criterion. These were the only systematic features in $V_{w+j} - V_w$ that attained the 5 per cent significance level over any of the three stations.

Discussion and conclusions. The mechanism causing the decrease in 200-mb and 250-mb easterlies near wet days over Gan during May to October cannot have been geopotential height increases resulting from latent-heat release, because such a mechanism would have caused an effect of similar magnitude during November to April. The most likely cause of the decreased easterlies is advection of air by mean upwards motion associated with the rainfall. This advection will have reduced the easterly components because at these levels the mean easterlies decrease downwards (Figure 1(b)). This mechanism could also have given the very much weaker effects of the same type at 200 mb and 250 mb in November to April (Figure 1(c); see also Table I), when the mean vertical shear of zonal wind was weaker but in
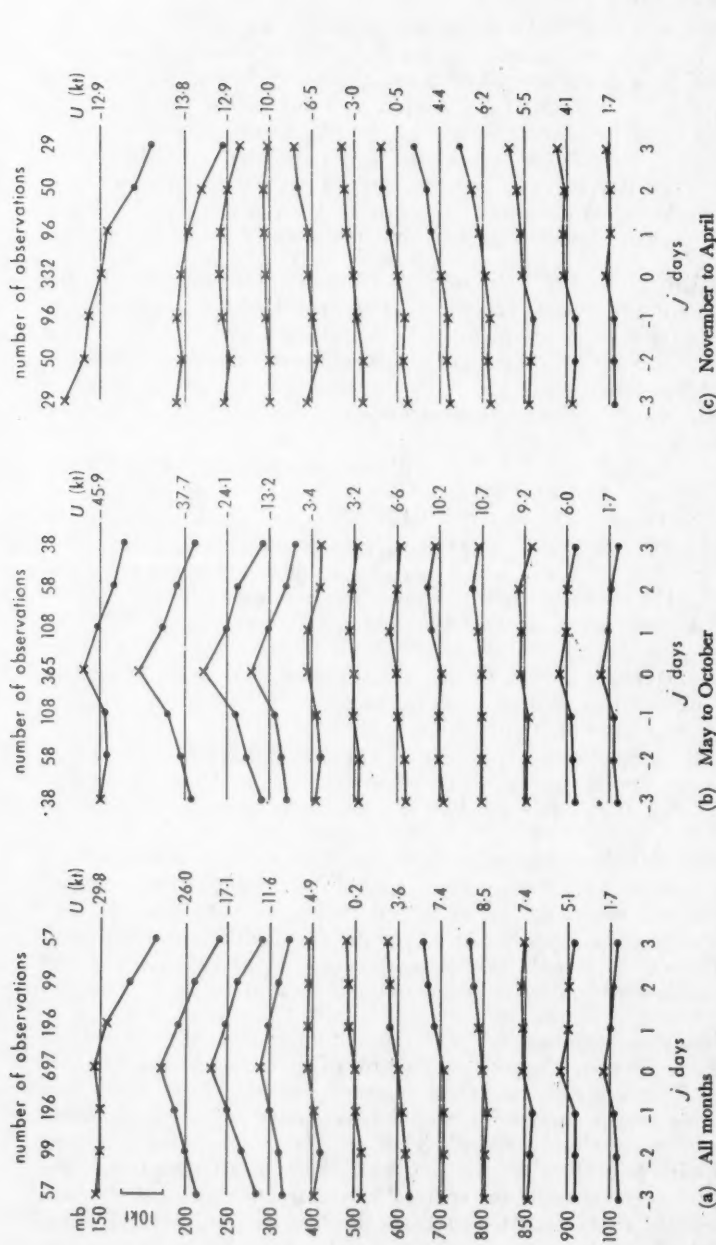
FIGURE 1—MEAN ZONAL WINDS U_{10+j}, j DAYS AFTER WET DAYS AT GAN FOR 1960–64 IN RELATION TO THE MEAN ZONAL WINDS U FOR THIS PERIOD

(a) All months   (b) May to October   (c) November to April

● indicates $U_{10} - U_{10+j}$ was found to be significantly different from zero at the 5 per cent level under the assumption that all the relevant data were independent and compatible with a Gaussian distribution.

Wet days are days with 1 mm or more of rain.

TABLE I—MEAN ZONAL WINDS ON WET AND DRY DAYS AT GAN

knots

Level mb	January Wet	January Dry	January Difference	April Wet	April Dry	April Difference	July Wet	July Dry	July Difference	October Wet	October Dry	October Difference
150	−18	−16	−2	−6	−6	0	−49	−56	7*	−35	−33	−2
200	−15	−18	3	−6	−9	3	−31	−42	11*	−23	−27	4
250	−13	−16	3	−6	−8	2	−18	−31	13*	−13	−18	5*
300	−11	−12	1	−5	−7	2	−10	−21	11*	−7	−12	5*
400	−6	−8	2	−4	−5	1	1	1		2	4	2
500	0	4	4*	3	−4	1	5	6	3	3	4	1
600	4	1	3*	1	2	1	8	12	4*	6	8	2
700	7	7	0	2	3	0	9	13	4*	10	11	2
800	8	7	0	4	4	0	6	11	5*	13	11	2
850	7	7	0	5	4	1	4	6	2	14	9	3*
900	5	3	2	5	3	2*	2	1	1	13	4	4*
1010 (surface)	1	1	0	3	—	2*	1	2	1	7		3

Wet ≥ 1 mm rainfall; dry < 1 mm rainfall.

Positive differences indicate that the zonal wind was more westerly on wet days than on dry days. An asterisk indicates that wet- and dry-day means were found to be different at the 5 per cent level of significance.

the same sense. Over Port Victoria the mechanism may well have been obscured by complex orographic effects (see also Wright and Ebdon[2]). Over Nairobi mean vertical shears of zonal wind are weak and orographic effects are complex and strong.

There is no obvious reason for the lower and mid-tropospheric increasing westerlies over Gan in November to April shown in Figure 1(c). The significant meridional wind changes found over Port Victoria and Nairobi could have been of orographic origin.

A very recent treatment of a closely related subject has been given by Holton and Colton.[3]

Acknowledgement. The author is much indebted to Mr D. W. Dent who commenced this work.

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REVIEW

Atmosphere–ocean interaction, by E. B. Kraus. 260 mm × 140 mm, pp. viii + 275, *illus.,* Clarendon Press: Oxford University Press, Ely House, 37 Dover Street, London, W1, 1972. Price: £7·50.

Air–sea interaction includes processes with scales ranging from, for example, the transport of heat and moisture from the sea surface to the air in immediate contact, to feedback processes that maintain anomalous sea surface temperatures and weather patterns over very large areas of a hemisphere for considerable lengths of time. Its importance as a link in maintaining the general circulation has long been recognized and in recent years it has been thought worth while to carry out elaborate experiments to try to provide some understanding of the processes such as those which enable the energy released over the tropical oceans on the microscale to be transferred to scales of hundreds or thousands of kilometres. A variety of phenomena such as wave-generation, seasonal thermocline development, storm surges and hurricane development, to mention but a few, all come within the scope of air–sea interaction. Increasing awareness of the importance of this field has stimulated a very rapid increase in the number of workers investigating these and similar topics in recent years. Somewhat surprisingly there has been a notable lack of corresponding text-books giving a wide-ranging and up-to-date description of the subject; the publication of this volume is therefore very welcome.

The book begins with a rather condensed introduction to the fluid-mechanical concepts required for appreciation of some of the material which follows. The second chapter discusses properties of sea water, spray, and sea ice, moist air and the interfacial layer, and this is followed by a section dealing with some relevant topics of solar and terrestrial radiation such as emission

and reflection from the sea surface, and penetration of radiation into the sea.

The material of Chapter 4 will be less familiar to most meteorologists; here the properties of surface waves are described and theories of their generation by the surface wind are discussed.

The next two chapters describe turbulent transfer near the interface, and the role of turbulent transports on a somewhat larger scale in controlling the structure of the boundary layers above and below the interface.

The volume concludes with a description of a number of three-dimensional interactions of widely differing character; it includes *inter alia* effects of sea surface temperature on the dynamics of the tropical atmosphere and the response of oceans to storms.

A few minor criticisms of the book can be made, for example the author's decision not to incorporate a review of the role of air–sea interaction in climatic change, and in the fifth chapter, an inadequate discussion of the recent evidence for breakdown of the Jacob's (bulk-aerodynamic) formulation for turbulent transfer of sensible heat from the oceans in regions with high specific humidity. Perhaps more important is the overall impression that the author has attempted to write about more topics than can be conveniently summarized in the space of about 250 pages; a substantially larger volume would have allowed a rather less breathless treatment of some of the subject-matter. These few points will not prevent the book rightly becoming essential reading for all students of air–sea interaction; they will notice a number of misprints and may wonder whether the price of the volume would not have justified the use of a more satisfactory paper than the traditional buff colour of the Oxford University Press.

N. THOMPSON

OFFICIAL PUBLICATIONS

The following publications have recently been issued :
Geophysical Memoirs
No. 117. Northern hemisphere monthly mean 500-millibar and 1000–500-millibar thickness charts and some derived statistics (1951–66). By B. J. Moffitt and R. A. S. Ratcliffe, M.A.

This publication describes the climatology of the 500-mb level and the 1000–500-mb thickness over much of the northern hemisphere using data from many sources for the period 1951 to 1966. Problems associated with the quality control of these data are discussed and an empirical method of deducing 1000–500-mb thickness given only 500-mb height and surface pressure is explained.

Charts include means for each month, currently used in support of long-range forecasting, and their variability in January, April, July and October together with monthly extreme maxima and minima of 1000–500-mb thickness. Extreme values of 500-mb height are also included in tabular form.

Brief mention is made of the annual and spatial variation in the frequency distribution of the data.

Scientific Paper

No. 33. Hydromagnetic waves on a beta-plane: a numerical study of the dispersion relationship. By R. Hide, Sc.D., F.R.S. and M. V. Jones, B.Sc.

Effects due to general rotation of waves in a bounded electrically-conducting fluid pervaded by a magnetic field are of considerable interest in theoretical geophysics and astrophysics. This publication illustrates how, although the general intractability of the governing mathematical equations is the principal obstacle to progress in the study of these effects, in one particular case, namely waves in a thin spherical shell of fluid pervaded by a toroidal magnetic field, the results of a recent exact analysis by Stewartson and Rickard can be used to show that the approximate but explicit dispersion relationship proposed previously by Hide on the basis of a simple physical model is probably valid over a wide range of conditions. Detailed properties of these waves are revealed by a numerical analysis of the dispersion relationship. The analysis is greatly simplified by measuring length and time in suitable units, thus reducing the number of free parameters from three to only one — the orientation of the magnetic field.

ROYAL SOCIETY AWARDS TO THE DIRECTOR-GENERAL

The Royal Society has awarded its Rumford Medal to Dr B. J. Mason, F.R.S., the Director-General of the Meteorological Office, for 'his distinguished contributions to meteorology, especially the physics of clouds'.

The medal and prize were founded by a gift from Count Rumford, F.R.S., in 1796, 'the income to be given as a premium every second year to the author of the most important discovery in any part of Europe: especially in Heat and Light.' The silver-gilt medal is accompanied by a prize of £200.

This award follows closely on Dr Mason being elected in 1971 to give the Bakerian Lecture, founded in 1775, this being accompanied by a Mr and Mrs John Jaffé Prize of £200.

OBITUARY

It is with regret that we have to record the death of Mr N. R. Broadbear, Assistant Scientific Officer, Exeter Airport, on 8 September 1972.

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NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General Meteorological Office, London Road, Bracknell, Berkshire, RG12 2SZ, and marked "for Meteorological Magazine."

The responsibility for facts and opinions expressed in the signed articles and letters published in this magazine rests with their respective authors.

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